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THE DEGRADED STATES

WEAPONS ANALYSIS RESEARCH SIMULATION (DSWARS):

AN INVESTIGATION OF THE DEGRADED STATES VULNERABILITY

METHODOLOGY IN A COMBAT SIMULATION

GARY RUSSELL COMSTOCK

FEBRUARY 1991

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DSWARS (Degraded States Weapons Analysis Research Simulation) is a ground-based combat simulation model written to implement the Ballistic Research Laboratory's (BRL) new vulnerability metrics using degraded states. The new metrics replace the standard mobility and firepower kill values derived from "averaging" probabilities and percent of functional loss (SDAL - Standard Damage Assessment List) values. They provide probabilities of a system being in a specific "degraded-state," which are defined by a series of fault-trees or deactivation diagrams of particular system components which are non-operational. The new metrics allow for many degradations of intermediate states besides the current "all or none" functionality. DSWARS model results using the degraded states methodology are compared to results using the SDAL vulnerability metrics.

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The Degraded States Weapons Analysis Research Simulation (DSWARS): An Investigation of the Degraded States Vulnerability Methodology in a Combat Simulation

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1 Introduction

AMSAA's **DSWARS** model is a ground combat simulation written to implement the Ballistic Research Laboratory's (BRL) new degraded states vulnerability metrics. The new metrics replace the standard mobility and firepower kill values derived from "averaging" probabilities and percent of functional loss (SDAL – Standard Damage Assessment List) values. They provide probabilities of a system being in a specific *degraded state*, which are defined by a series of fault-trees or deactivation diagrams of particular system components which are non-operational. The new metrics allow for many degradations of intermediate states besides the current "all or none" functionality.

DSWARS also permits the use of conventional SDAL vulnerability as input as well as the new Degraded States (DS) vulnerability. It was written in C, developed on a SUN-4 Workstation, and uses dynamic memory allocation to handle the theoretically possible 18 million data values per vulnerability file. It consists of about 15,000 lines of code and 150 routines. DSWARS uses decision tables to determine subsystem transition states and to determine weapon system tactics and performance changes due to the effect of the state transitions.

1.1 Background

In 1988, the Ballistic Research Laboratory (BRL) and the Army Materiel Systems Analysis Activity (AMSAA) began a joint program to develop improved metrics for expressing the results of vulnerability assessments, and to implement these metrics in a force level model.[1]

Traditional vulnerability calculations make use of a mapping procedure called *damage assessment lists* (DALs) or *standard damage assessment lists* (SDALs). A DAL maps killed components and sets of components into *degradation of combat utility* (DCU). However, the use of DALs in the process of developing vulnerability measures of effectiveness is conceptually and mathematically problematic. [2] [3]

The Degraded States (DS) methodology overcomes the problems associated with the DAL, and provides a more robust account of vehicle capability as a function of specific damage sustained.

2 Model Development

AMSAA's **Groundwars** [4] model was chosen as a basis for the level of modeling desired for the development of DSWARS. The Groundwars level of resolution and collection of critical events was used during the initial DSWARS design phase.

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[1] J. Abell, L. Roach, M. Starks, "DEGRADED STATES VULNERABILITY ANALYSIS," BRL Technical Report BRL-TR-3010, June 1989.

[2] J.R. Rapp, "An Investigation of Alternative Methods for Estimating Armored Vehicle Vulnerability," BRL Technical Report BRL-MR-03290, July 1983.

[3] M.W. Starks, "New Foundations for Tank Vulnerability Analysis," *The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association (ADPA)*, held at the Naval Ocean Systems Center, San Diego, CA, 10-12 May 1988.

[4] M.C. Schmidt, G.R. Comstock, [illegible] R.J. Burns, "GROUNDWARS 4.0 USER'S GUIDE," AMSAA Technical Report No. 478, October 1988.

2.1 Groundwars

Groundwars is an outgrowth of **TANKWARS**, a model originally developed by BRL [5]. It was written in FORTRAN 77 and has been modified by AMSAA over a period of years to incorporate other weapon systems besides tanks, and to include the modeling of new critical events and modified treatment of other events and weapon system capabilities. [6] Groundwars is a Monte Carlo, two-sided, event-sequenced weapon systems effectiveness model which provides the results of a ground duel between two homogeneous forces.

2.2 Groundwars Vulnerability Methodology

Groundwars models weapon system vulnerability based on three different kinds of expected-value "kills", Mobility (M), Firepower (F), and Catastrophic (K). BRL provides the following DAL-based vulnerability metrics as input to Groundwars:

- M-Kill (includes M-only, M-and-F, and K)
- F-Kill (includes F-only, M-and-F, and K)
- M/F-Kill (includes M-only, F-only, M-and-F, and K)
- K-Kill (includes K-Kill only)

Before the combat simulation begins, Groundwars converts these metrics into the following mutually exclusive measures:

- M-only Kill
- F-only Kill
- M-and-F Kill
- K-Kill
- No-Kill (1 minus the sum of all kill types)

It must be pointed out that this conversion assumes independence for the BRL calculations which is not mathematically correct, but illustrates the problems inherent with the DAL-based metrics.

The five Groundwars kill categories are added to form a cumulative distribution which sums to a value of one. To assess the effect of a hit on the target, a uniform (0,1) random number is drawn and damage is assigned to the target according to the kill category from the distribution.

2.3 DSWARS

The *Degraded States Weapons Analysis Research Simulation* (DSWARS) model was developed as an extension of Groundwars. However, it was designed with the concept of the degraded states and heterogeneous forces. Since the kill categories of Groundwars are a subset of the degraded states

[5] F. Bunn,"THE SUSTAINED COMBAT MODEL: TANK WARS II, An Armored Combat Analysis Program," BRL Technical Report ARBRL-TR-09999, December 1985.

[6] G.R. Comstock, "AMSAA Duel Modeling Improvements," presented at the Army Operations Research Symposium XXVI, Ft. Lee, VA, 13-15 October 1987.

which were defined and used in the study, DSWARS can also accept the DAL-based metrics as input and so can be run in a Groundwars "mode".

A concern during the early design of DSWARS was the trade-off between establishing a robust set of degraded states metrics and the computer memory needed for the storage of the set of degraded states probabilities for the range of conditions needed for a satisfactory modeling of the ground combat conditions for a game's scenario. This aspect of attempting to model vulnerability in finer resolution in combat simulation models has been a concern for a number of years.[7] [8]

The typical BRL DAL-based vulnerability files used for Groundwars contain the probability values for each combination of the following conditions:

- 2 exposures (fully exposed or defilade)
- 10 round dispersion values (1 to 10 feet)
- 7 view angles of the incoming round (0, 30, ..., 180 degrees)
- 6 ranges of engagement (500, 1000, ..., 3000 meters)

Since it was decided that DSWARS would use 75,600 different degraded states, and since the model would need a set of DS probabilities for each combination of the above conditions, we can calculate:

$$75,600 \times 2 \times 10 \times 7 \times 6 = 63,504,000$$

values per file or array. It was decided to cut the number of dispersions to five (1,2,3,5 and 10), and the view angles to four (0 to 90 degrees). This reduced the total combinations to about 18 million values per array.

Since it was anticipated that not all possible degraded states would be realized in practice (i.e., improbable combinations of damaged components), and that many more would hopefully be near-zero in value, it was decided that the DSWARS would be written in the C language using ***dynamic memory allocation***.[9] This would minimize the necessary computer storage during runtime by only allocating memory for the states as needed. In anticipation of a possible large growth in the size of the new model's event-processor queue due to more live (but somewhat damaged) weapon systems participating in the battle, the Groundwars ***linked-list*** event queue data structure was replaced with ***heaps*** [10] [11] in an attempt to speed up the model's search and deletion of events. In order to minimize the complexity of conditional code needed for altering weapon performance and tactics during the game due to changing states, ***decision tables*** were used [12] to track state transitions and state effects in terms of performance and tactics changes. The model was developed on a SUN-4/110 Workstation under *SunView/UNIX* using *dbxtool* [13]. Currently, DSWARS consists of about 15,000 lines of code and 150 routines. Many new output measures to report on the end-of-game weapon states had to be developed to aid in the analyses. These were added to the list of output measures incorporated from the Groundwars model.

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[7] G.R. Comstock, "Extending the Cascade Approach for use in Combat Simulation Models," RARDE WP 30/82 (MA4), Royal Armament Research and Development Establishment, U.K., March 1983.

[8] N. Roberts, "Target Degradation Modes in Combat Simulations," RARDE DWP 8/87 (CA4), Royal Armament Research and Development Establishment, U.K., July 1987.

[9] B.W.Kernighan and D.M. Ritchie, *The C Programming Language*, Bell Laboratories, Murray Hill, NJ, 1978.

[10] D.E. Knuth, *The Art of Computer Programming, Volume 3: Sorting and Searching*, 1973.

[11] E. Horowitz and S. Sahni, *Fundamentals of Computer Algorithms*, 1978.

[12] R. Welland, *Decision Tables and Computer Programming*, 1981.

[13] *Dbxtool* is the SunView window-based source-level debugger for the SUN Workstation.

3 Degraded States Modeling

3.1 Degraded States

The tradition has long been to describe vehicle loss of function in terms of mobility and firepower. For the DS approach, the functions of a tank were divided into six ***subsystems:*** mobility, firepower, acquisition, crew, communication, and ammunition. Each subsystem was further divided into a number of degraded subsystem states which described various capabilities of the tank with respect to the particular subsystem. Each state was assigned a degraded subsystem state name (e.g., M_2 is the name given to the Mobility Subsystem State which is defined as a significant reduction of speed). Each subsystem contains a "no damage" state and a series of degraded states. In most subsystem categories, combinations of states can occur. For example, F_9 represents a combination of states F_2, F_3, and F_4 all occurring simultaneously. A complete list of the subsystems and their degraded states is shown in table 1. The list was developed jointly by BRL and AMSAA. The total number of combinations possible was calculated by multiplying the number of degraded states within each subsystem. This is shown at the bottom of table 1.

Table 1: **LIST OF DEGRADED STATES**

SUBSYSTEM MOBILITY	SUBSYSTEM FIREPOWER
M_0 - No mobility damage	F_0 - No firepower damage
M_1 - Reduced maximum speed (slight)	F_1 - Loss of main armament
M_2 - Reduced maximum speed (significant)	F_2 - Unable to fire on the move
M_3 - Stop after time t	F_3 - Increased time to fire
M_4 - Total immobilization	F_4 - Reduced delivery accuracy
M_5 - M_1 and M_3	F_5 - Loss of secondary armament
M_6 - M_2 and M_3	F_6 - F_2 and F_3
SUBSYSTEM CREW	F_7 - F_2 and F_4
C_0 - 0 crew casualties	F_8 - F_3 and F_4
C_1 - 1 crew casualty	F_9 - F_2 and F_3 and F_4
C_2 - 2 crew casualties	F_{10} - F_2 and F_5
C_3 - 3 crew casualties	F_{11} - F_3 and F_5
C_4 - 4 crew casualties	F_{12} - F_4 and F_5
SUBSYSTEM COMMUNICATION	F_{13} - F_2 and F_3 and F_4 and F_5
X_0 - No communication damage	F_{14} - F_2 and F_3 and F_5
X_1 - No internal communication	F_{15} - F_2 and F_4 and F_5
X_2 - No external communication > 300 feet	F_{16} - F_3 and F_4 and F_5
X_3 - No external communication	F_{17} - F_1 and F_5 (total loss of firepower)
X_4 - X_1 and X_2	SUBSYSTEM AMMUNITION
X_5 - X_1 and X_3	K_0 - No ammo lost
SUBSYSTEM ACQUISITION	K_1 - Bustle ammo lost
A_0 - No acquisition damage	K_2 - Hull ammo lost
A_1 - Reduced acquisition capability	K_3 - K_1 and K_2
A_2 - Unable to acquire while moving	K_4 - K kill
A_3 - A_1 and A_2	

Note: The total possible number of degraded states is

$$7 \times 18 \times 4 \times 5 \times 6 \times 5 = 75,600$$

Where a given state indicates a change in performance level (rather than a complete loss of a particular capability), the magnitude of change is supplied by user input.

3.2 DS Vulnerability File Format

The new DS Vulnerability files generated by BRL [14] consist of the DS probabilities for a given projectile/target, for six ranges, two target exposure levels, five round dispersion values, and four incoming round angles. Table 2 shows a sample file. The probabilities correspond to degraded states for which the individual subsystem state values are also listed. Degraded states are only listed if the DS probability under any of the four view angles are greater than zero (or near zero). Thus, there are usually different sets of degraded states collections for the various sets of condition combinations. The methodology used to develop the probabilities was an adapted form of BRL's current Monte Carlo vulnerability code for point burst modeling, **SQuASH** (Stochastic Quantitative Analysis of System Hierarchies) [15] [16] [17], developed by the Vulnerability Methodology Branch (VMB) of BRL.

Table 2: **SAMPLE DEGRADED STATES VULNERABILITY FILE**

RANGE (METERS)	EXP	DISP (FEET)	SUBSYSTEM DAMAGE M F A C X K	PROBABILITY BY VIEW ANGLE (DEG) 0	30	60	90
500	F	1	0 0 0 0 0 0	.286	.294	.328	.290
500	F	1	2 1 3 2 5 0	.056	.082	.071	.090
500	F	1	4 8 3 0 0 1	.049	.058	.077	.101
500	F	1	2 1 3 0 5 0	.044	.052	.069	.922
...	.	.	. . . . . .	......	......	......	......

Notes. DS Subsystem Headings:
M - Mobility F - Firepower
A - Acquisition C - Crew
X - Communication K - Ammunition

Repeat for
dispersions of 1, 2, 3, 5, 10 feet,
target exposure of F (fully exposed) and D (defilade),
firer/target ranges of 500, 1000,..., 3000 meters.

3.3 Degraded States in DSWARS

DSWARS' method of determining target damage is similar to the Groundwars treatment. All degraded states probabilities (for a given range, target exposure, dispersion, and view angle) are added to form a cumulative distribution which sums to a value of one. To assess the effect of a hit on the target, a uniform (0,1) random number is drawn and a *provisional* degraded state is assigned to the target according to the DS drawn from the distribution.

A tank's state at any time is described by its values in each subsystem state (mobility (M), firepower (F), acquisition (A), crew (C), communication (X), and ammunition (K)). For example, a tank begins a battle in the null state:

$$M_0 \quad F_0 \quad A_0 \quad C_0 \quad X_0 \quad K_0.$$

[14] J.M. Abell, M.D. Burdeshaw, and B.A. Rickter, "DEGRADED STATES VULNERABILITY ANALYSIS: PHASE II," BRL Technical Report BRL-TR-3161, October 1990.

[15] A. Ozolins, "Stochastic High-Resolution Vulnerability Simulation for Live-Fire Programs," *The proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association (ADPA)*, held at the Naval Ocean Systems Center, San Diego, CA, 10-12 May 1988.

[16] P.H. Deitz and A. Ozolins, "Computer Simulations of the Abrams Live-Fire Field Testing," presented at the Army Operations Research Symposium XXVII, Ft. Lee, VA, 12-13 October 1988.

[17] P.H. Deitz and A. Ozolins, "HIGH-RESOLUTION VULNERABILITY METHODS AND APPLICATIONS," BRL memorandum Report BRL-MR-3876, November 1990.

Here each subsystem state is set to 0 indicating no damage. Later in the battle, after receiving one or more hits, the tank may reach the following state:

$$M_1 \quad F_2 \quad A_0 \quad C_1 \quad X_3 \quad K_0.$$

At this point, the tank's maximum speed capability is slightly reduced (M_1), it is unable to fire on the move (F_2), it has suffered one crew casualty (C_1), and it has lost the capability of external communication (X_3).

When assessing subsequent shot damage to a target, each subsystem value of the provisional DS as drawn from the distribution is compared to its previous value. Four types of situations may occur as follows:

- If the new subsystem value represents a *more severe* degradation of a particular capability or capabilities, the new subsystem value is assigned the *drawn* value.
- If the new subsystem value represents a *less severe* degradation of a particular capability or capabilities, the new subsystem value is assigned the *previous* value.
- If the new subsystem value indicates a damage category which is different in *type* to the previous value's damage category, then the new subsystem value is assigned a value which represents the *combination* of the two subsystem types.
- If the new subsystem value indicates a *different combination* of damage categories compared to the previous value's categories, then the new subsystem value is assigned a value which represents the more *severe combination* of the two subsystem types.

For example, suppose a tank has the following degraded state:

$$M_1 \quad F_6 \quad A_0 \quad C_0 \quad X_0 \quad K_0.$$

Next, suppose the target receives a hit, and a random number indicates the *provisional* DS state is:

$$M_2 \quad F_2 \quad A_0 \quad C_0 \quad X_0 \quad K_0.$$

A comparison of subsystem Mobility indicates a *more severe* degradation of capability of vehicle speed, so the new M value becomes M_2. However, a comparison of the subsystem Firepower values indicates a *less* severe combination of firepower damage, so the new F value remains F_6. The target's new degraded state is thus:

$$M_2 \quad F_6 \quad A_0 \quad C_0 \quad X_0 \quad K_0.$$

3.4 DSWARS Tactics and Performance Changes for Specific Degraded States

When a weapon system changes to a new degraded state, not only must its new capabilities in terms of performance be reflected, but also the ramifications of its new restricted operation in terms of tactics. The following performance and tactics changes were programmed to reflect the listed degraded states:

- **SUBSYSTEM MOBILITY**(input attacker speed = 5.56 mps)

M_1 : **Reduced speed (slight)**

- degrade maximum speed to 80 percent (4.44 mps)
- stretch los (line-of-sight) times already scheduled

M_2 : **Reduced speed (significant)**

- degrade maximum speed to 30 percent (1.67 mps)
- stretch los (line-of-sight) times already scheduled
- if can still move and fire,
  cancel any current engagements
  cancel any already scheduled detections
  schedule overwatch

M_3 : **Stop after time t**

- not played for this study

M_4 : **Total immobilization**

- cancel future los changes for this unit
- if unit cannot fire, consider dead, redirect attackers

- **SUBSYSTEM FIREPOWER**

F_1 : **Loss of main armament**

- cancel any engagements and future detections
- cancel all future detections, engagements of this tgt by enemy units
- schedule new search for each enemy unit that was engaging this tgt
- if can move, schedule hide
- if can't move, consider dead, redirect attackers

F_2 : **Unable to fire on the move**

- change to halt-to-fire

F_3 : **Increased time to fire**

- add 10 secs (input) to first and subsequent fire times

F_4 : **Reduced delivery accuracy**

- degrade delivery accuracy (change from GPS/LR to GAS/noLR)

- **SUBSYSTEM ACQUISITION**

A_1 : **Reduced acquisition capability**

- degrade p-infinity, t-bar, p-pinpoint (change from either OPT or TIS to binoculars)
- cancel any current engagements
- cancel any already scheduled detections

A_2 : **Unable to acquire while moving**

- cancel any current engagements
- cancel any already scheduled detections
- schedule overwatch

- **SUBSYSTEM CREW**

C_1 : **1 crew casualty**

- immediate delay effect (input 120 secs):

cancel any current engagements
cancel any already scheduled detections
schedule new search after delay time
- degrade existing max speed to 85 percent and
- stretch los (line-of-sight) times already scheduled

C_2 : **2 crew casualties**

- immediate delay effect (input 120 secs):
  cancel any current engagements
  cancel any already scheduled detections
  scheduie new search after delay time
- multiply attacker fire times by 3 (first and subsequent rounds)
- degrade existing max speed to 75 percent and
- stretch los (line-of-sight) times already scheduled
- change tactic to disengage target after each round, and require re-acquisition before new engagement

C_3 : **3 crew casualties**

- immediate delay effect (input 120 secs):
  cancel any current engagements
  cancel any already scheduled detections
- degrade existing max speed to 70 percent and
- stretch los (line-of-sight) times already scheduled
- if can move, schedule hide after the delay; else abandon vehicle

C_4 : **4 crew casualties**

- consider dead, redirect attackers

- **SUBSYSTEM COMMUNICATION**

X_1 : **No internal communication**

- degrade time to fire first round by adding 10 secs (input)
- degrade time to hide by 10 secs (input)

- **SUBSYSTEM AMMUNITION**

K_1 : **Bustle ammo lost**

- multiply original fire times by 2 (first and subsequent rounds)
- if no ammo left and can move, schedule hide

K_2 : **Hull ammo lost**

- if no ammo left and can move, schedule hide

K_3 : **Bustle and Hull ammo lost**

- if can move, schedule hide

K_4 : **K-kill**

- consider dead, redirect attackers

3.5 DSWARS Degraded States Transition Tables

Given a unit's (weapon system's) current ***substate*** (subsystem state value), and given the provisional or *drawn* degraded substate determined by random number and sampled from the DS Vulnerability File, the *DS Subsystem Transition Table* describes the resulting degraded subsystem state. Thus, we can describe the function

$$New\ Substate = F(Current\ Substate, Drawn\ Substate)$$

Table 3 shows the Transition Table for Subsystem Mobility.

Table 3: **SUBSYSTEM TRANSITION TABLE FOR MOBILITY**

DRAWN SUBSTATE VALUE	CURRENT SUBSTATE						
	M_0	M_1	M_2	M_3	M_4	M_5	M_6
M_0	0	1	2	3	4	5	6
M_1	1	1	2	5	4	6	6
M_2	2	2	2	6	4	6	6
M_3	3	5	6	3	4	6	6
M_4	4	4	4	4	4	4	4
M_5	5	5	6	5	4	5	6
M_6	6	6	6	6	4	6	6

As an example, if a unit's current Mobility Substate is M_3, and a random number draw gives a provisional substate value of M_2, we access the Mobility Transition Table to find that

$$New\ Mobility\ Substate = F(M_3, M_2) = M_6$$

3.6 DSWARS State-Effect Tables

The DSWARS ***State-Effect Tables*** determine what tactics and performance changes are needed following a hit and drawn degraded state for a unit. The State-Effect tables are accessed to find the corresponding ***effect-flag*** differences between the unit's old and new degraded states. Each state-effect flag signifies a particular set of performance and tactics changes. Whether a tactic or performance change is needed is determined by comparing the set of state-effect flags for both the previous and new substate values. Whether a state effect is set is a function of both the previous substate value and the ***flag-type*** within the subsystem class. Thus, we have

$$State\ Effect = F(Old\ Substate, Flag\ Type)$$

Table 4 shows the State-Effect Table for Subsystem Mobility. Table 5 shows the Subsystem Mobility flag-types.

Only when a state effect has not been set previously, but the State-Effect function indicates it must be set for the new substate value, do tactics and performance changes take place.

For example, suppose a unit's previous Mobility Substate was M_3, and the unit's new Mobility Substate value after accessing the State Transition Table is M_6. Each flag-type must be checked in conjunction with both the previous substate value (M_3) and the new substate value (M_6). Since there are four flag-types for Subsystem Mobility, we find that:

$$
\begin{array}{lll}
F(M_3, m_1) = FALSE & \text{and} & F(M_6, m_1) = FALSE \\
F(M_3, m_2) = FALSE & \text{and} & F(M_6, m_2) = TRUE \\
F(M_3, m_3) = TRUE & \text{and} & F(M_6, m_3) = TRUE \\
F(M_3, m_4) = FALSE & \text{and} & F(M_6, m_4) = FALSE.
\end{array}
$$

Only for flag m_2 do we have the (FALSE, TRUE) combination to signify that the tactics and performance changes for flag m_2 take place.

Table 4: **MOBILITY STATE-EFFECT TABLE**

	Current SubState						
Flag	M_0	M_1	M_2	M_3	M_4	M_5	M_6
m_1	0	1	0	0	0	1	0
m_2	0	0	1	0	0	0	1
m_3	0	0	1	0	0	1	0
m_4	0	0	0	0	1	0	1

Note: 1 = TRUE and 0 = FALSE

Table 5: **MOBILITY FLAG-TYPES**

Flags	Mobility SubState
	M_0 - No Damage
m_1	M_1 - Slight speed reduction
m_2	M_2 - Significant speed reduction
m_3	M_3 - Stop after time t
m_4	M_4 - Total Immobilization
m_1, m_3	M_5 - M_1 and M_3
m_2, m_3	M_6 - M_2 and M_3

4 DSWARS Cases

4.1 DS Input Files Used for the Study

The BRL generated Degraded States vulnerability files for a series of cases executed by AMSAA using DSWARS to address the differences between the current SDAL-based vulnerability values, and the new degraded states representation. These results will aid in a decision on wider application of the new DS metrics. The input files represent:

- a penetrating projectile vs modern tank frontal armor designated as P.
- a non-penetrating projectile vs modern tank frontal armor designated as N.

4.2 DSWARS/Groundwars Comparison

Before using DSWARS in the study, a comparison between DSWARS and Groundwars was undertaken in an attempt to verify that the new DSWARS code is an accurate representation of the

corresponding Groundwars code when DSWARS is run in the Groundwars mode. Although some Groundwars methodology was transferred to DSWARS with only a change in code (FORTRAN to C), some entirely new algorithms were used as well.

A set of eight cases were run with each model using identical input (SDAL vulnerability metrics). DSWARS was run in the Groundwars mode. The cases consisted of the four attacker/defender round combinations for visibility conditions of both 3 km and 7 km. The scenario portrayed 9 attackers vs 3 defenders. Figure 1 shows the results in terms of loss exchange ratio (bars), and individual losses for each side listed numerically. A loss is defined as a tank which is firepower killed (or worse). Results showed very good agreement indicating that the representation of the Groundwars combat methodology in DSWARS was successful.

4.3 DSWARS DS/SDAL Comparison

Cases were then executed using DSWARS with vulnerability data in both Degraded States form, and SDAL form, for a scenario consisting of 9 attacking tanks vs 3 defending tanks. Table 6 shows the base case matrix. The *Aggregate* vulnerability input is explained in section 12.

Table 6: **DSWARS BASE CASE MATRIX**

CASE	VULNERABILITY INPUT	ATTACKER ROUND	DEFENDER ROUND	VISIBILITY
1	SDAL	P	P	3 km
2	SDAL	P	N	3 km
3	SDAL	N	P	3 km
4	SDAL	N	N	3 km
5	Degraded States	P	P	3 km
6	Degraded States	P	N	3 km
7	Degraded States	N	P	3 km
8	Degraded States	N	N	3 km
9	Aggregate	P	P	3 km
10	Aggregate	P	N	3 km
11	Aggregate	N	P	3 km
12	Aggregate	N	N	3 km
13	SDAL	P	P	7 km
14	SDAL	P	N	7 km
15	SDAL	N	P	7 km
16	SDAL	N	N	7 km
17	Degraded States	P	P	7 km
18	Degraded States	P	N	7 km
19	Degraded States	N	P	7 km
20	Degraded States	N	N	7 km
21	Aggregate	P	P	7 km
22	Aggregate	P	N	7 km
23	Aggregate	N	P	7 km
24	Aggregate	N	N	7 km

Notes P Penetrating round vs frontal armor
N Non-penetrating round vs frontal armor
All cases were run with 9 attackers vs 3 defenders

Primary output measures analyzed consisted of:

- Complete firepower losses
- Partial firepower losses
- Complete mobility losses
- Partial mobility losses
- Any firepower losses (complete plus partial)
- Any mobility losses (complete plus partial)
- Complete Firepower Exchange Ratio, CFXR (ratio of attacker to defender complete firepower losses)
- Any Firepower Exchange Ratio, AFXR (ratio of attacker to defender any-firepower losses)
- Average number of detections, shots, and hits.

Sample DSWARS output from one set of cases is shown in table 7. End of game results are shown for both the DS and SDAL cases run for 9 attackers firing round N vs 3 defenders firing round N. Attacker/defender opening range was 4000 meters. The game was stopped when the first attacker closed to within 500 meters of any defender. In the table, losses are broken down by attacker and defender for various degraded substates. Additional detail of battle damage available from the Degraded States methodology can be seen.

4.4 Results

Figures 2 and 3 show exchange ratios (both AFXR and CFXR) and complete and partial firepower and mobility losses for various pairs of cases. In general, DSWARS results indicate that for tank versus tank, DS XR and SDAL XR differences are not practically significant. Although attacker and defender losses show some differences, they appear to be close enough in magnitude not to change the apparent winner or loser of a DSWARS battle. As expected, DS cases showed a decrease in complete losses, but the additional DS partial losses usually brought the DS total losses to more than the corresponding total SDAL losses. Table 8 shows the range of percent increase or decrease in various output measures when comparing SDAL to DS case results.

In an attempt to provide the conventional form of vulnerability metrics (SDAL) to the army community that users may still desire, whether for direct analysis or as input to higher level models, BRL has combined classes of the degraded states into another form, called *Aggregated* DS probabilities. These probabilities are defined in table 9. In an attempt to determine how these Aggregated DS probabilities compare to the actual SDAL values when used in a force level model, DSWARS cases were also executed using the Aggregated DS probabilities.

Figures 4 and 5 show exchange ratios, and complete and partial losses for the Aggregate cases along with the corresponding DS and SDAL cases. DSWARS results indicate that DS-Aggregated XRs also are not practically different from SDAL or DS XRs. However, complete DS-Aggregate losses are closer in value to the SDAL complete losses than to the DS complete losses.

4.5 Conclusions

Based on results seen from the series of DSWARS cases run to date, several conclusions can be drawn:

Table 7: **DSWARS DS/SDAL Case Results Comparison: 9 N vs 3 N, 7km Visibility**

State at End of Battle		Defender		Attacker	
		Ds	Sdal	Ds	Sdal
M_1	Slight speed reduction	.01		.22	
M_2	Significant speed reduction	.27		1.23	
M_4	Full mobility loss	.35	.96	3.30	5.40
F_1	Main gun loss	1.26		4.11	
F_8	Increased time to fire and reduced delivery accuracy			.09	
F_9	No moving fire, increased time to fire, reduced delivery accuracy	.34		1.63	
F_{17}	Loss of main, 2nd guns	.16	1.98	.20	5.36
A_1	Reduced acquisition	.27		.30	
A_2	No acquire on the move			.16	
A_3	Full acquisition loss	1.21		5.51	
K_1	Bustle ammo loss	.03		.20	
K_4	Catastrophic Kill	.16	.15	.20	.29
C_1	Loss of 1 crew	.35		2.00	
C_2	Loss of 2 crew	.35		1.06	
C_3	Loss of 3 crew	.34		.87	
C_4	Loss of 4 crew	.16		.20	
X_3	No external communication	.02		.02	
X_5	No internal nor external communication	.90		2.67	
No Damage		.91	1.00	1.57	2.28
Avg number of crew casualties		2.70		7.55	
Detections		30	24	16	13
Shots		41	33	51	45
Hits		26	21	12	10

Table 8: **Percent Change When Comparing SDAL to DS Case Results**

Measure	Percent Increase/Decrease
Complete Firepower Losses	−40 (max difference)
Complete Mobility Losses	−70 (max difference)
Any Firepower Losses	+25 (max difference)
Any Mobility Losses	+70 (max difference)
CFXR	−15 to +45
AFXR	−7 to +33
Detections, Shots, Hits	+25 (average)

Table 9: **Aggregated DS Definitions**

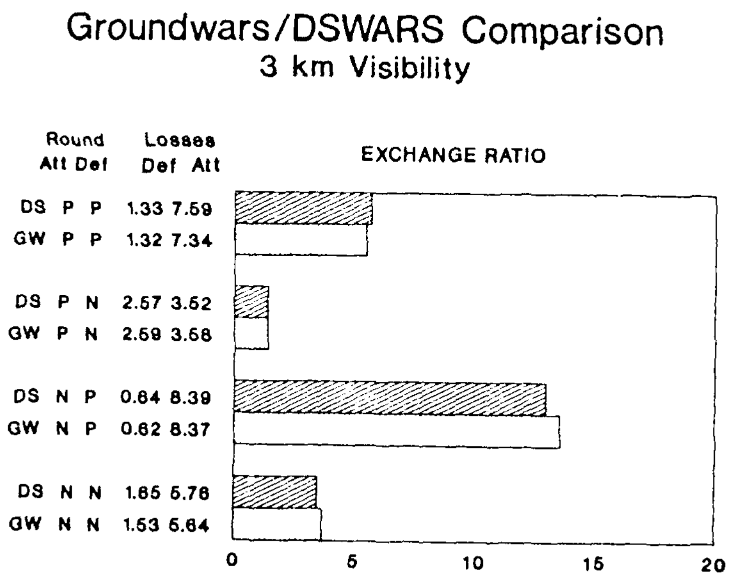
AGGREGATED DS	DS DAMAGE
M	Any M or C or X or K
F	Any F or C or X or K or A
M/F	Any M or F or C or X or K or A
K	K4

- Degraded States end-of-game results provide a fuller and more detailed picture of combat damage assessment.
- For tank-vs-tank cases, these results suggest that, historically, the past use of SDAL vulnerability metrics as though they were complete loss of function in force-level models has given numerically acceptable results.
- For tank-vs-tank cases, results indicate that DS-Aggregated probabilities can be used as an alternative to, or mixed and matched with, SDAL metrics.
- AMSAA sees no need for changing higher resolution force effectiveness models at this time.

5 Follow-on Efforts

The Ballistic Research Laboratory is continuing towards a full implementation of DS metrics with their Phase III and Phase IV programs. BRL Phase III will continue DS kill definition developments for both RED and BLUE heavy armor, IFVs, artillery, and helicopters, and will determine the best configuration for Vulnerability/Lethality codes to permit quick-turnaround DS estimates. Phase IV will depend on specific outcomes from their Phase III work.

AMSAA will continue to analyze DSWARS results to characterize differences (e.g., losses as a function of time, percentage of partially damaged tanks that fire another shot, end game criteria, additional statistical measures and testing, force ratio size sensitivity). Additional sensitivity analyses are planned to address DSWARS tactics, decision rules, and inputs. Other plans include the addition of missile code logic to DSWARS, a full heterogeneous force implementation, investigation of subsequent battle capability, and investigation of other anti-tank weapons in DSWARS as BRL files become available (e.g., ATGM, RPG, HE FRAG). A subsequent report is planned to be published which will list in detail all of the DSWARS output results by case, game results by time, and statistical testing of the DSWARS output.



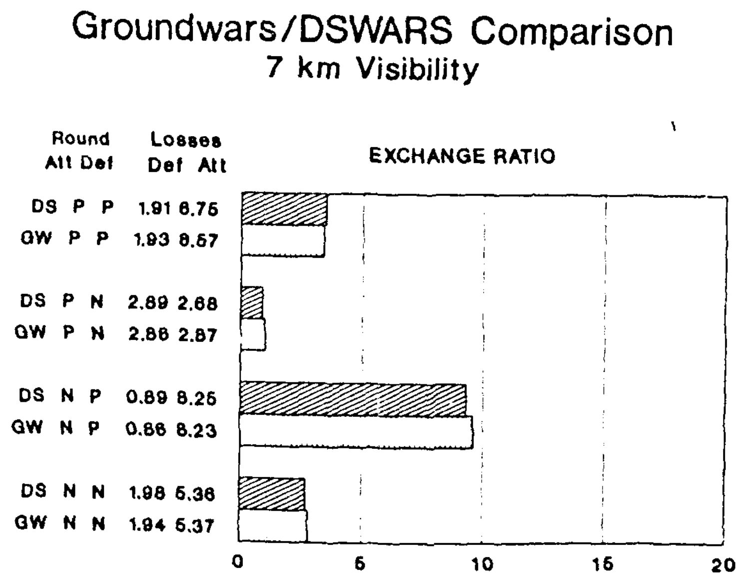


Figure 1. Groundwars/DSWARS Comparison

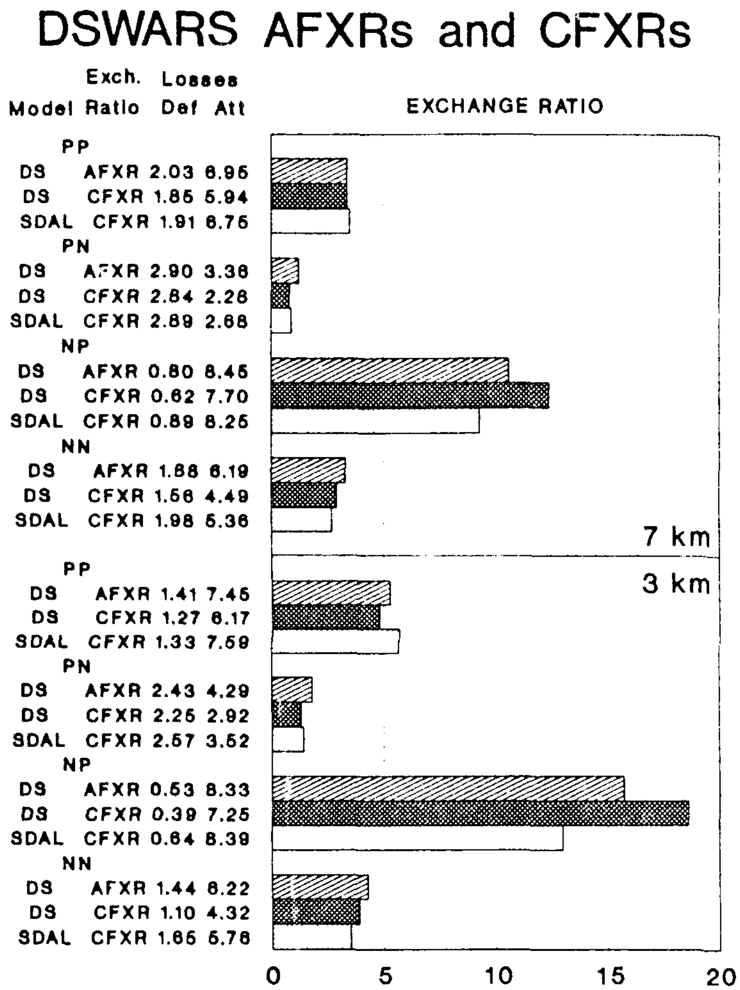


Figure 2. DSWARS AFXRs and CFXRs for DS and SDAL Cases

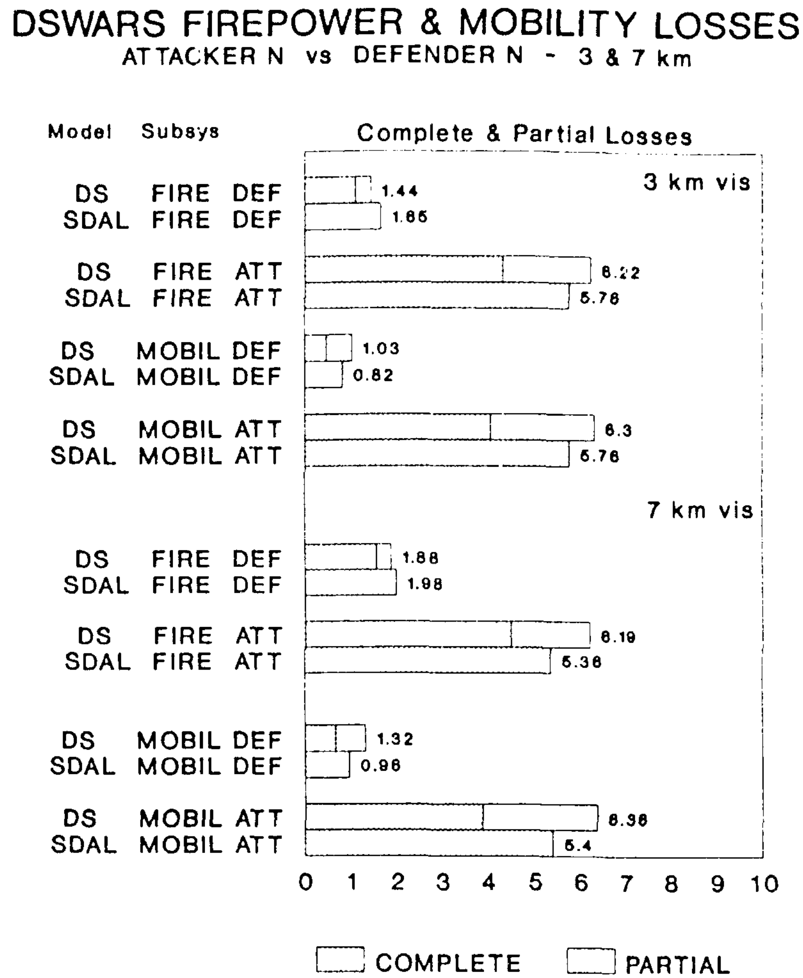


Figure 3. DSWARS Firepower and Mobility Losses

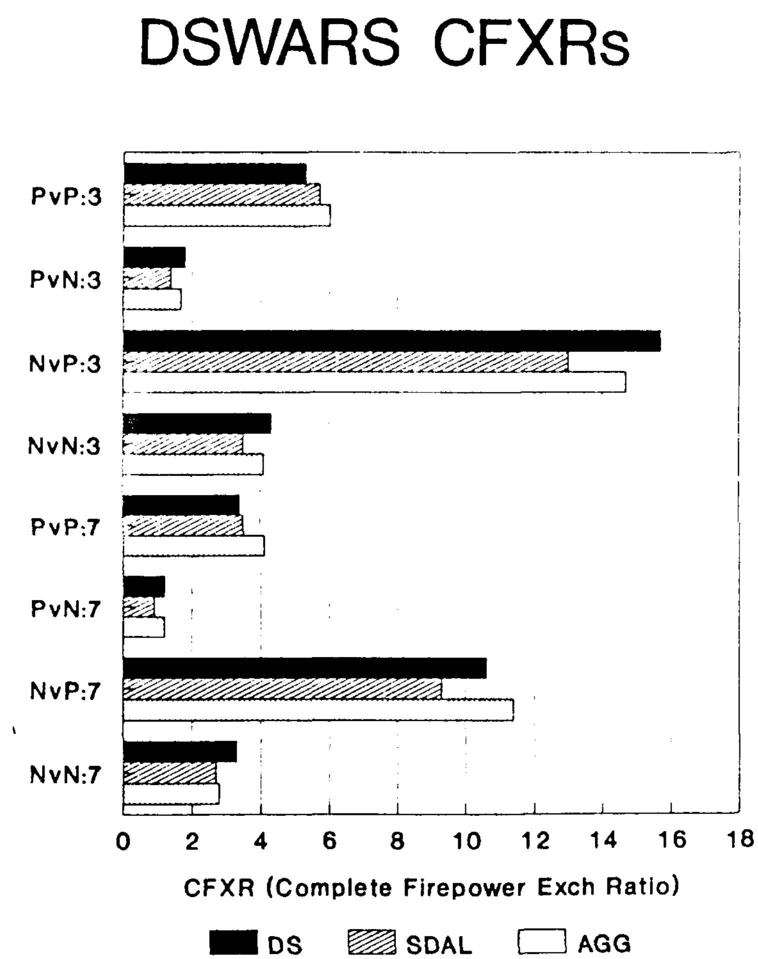


Figure 4. DSWARS CFXRs for DS, SDAL, AGG Cases

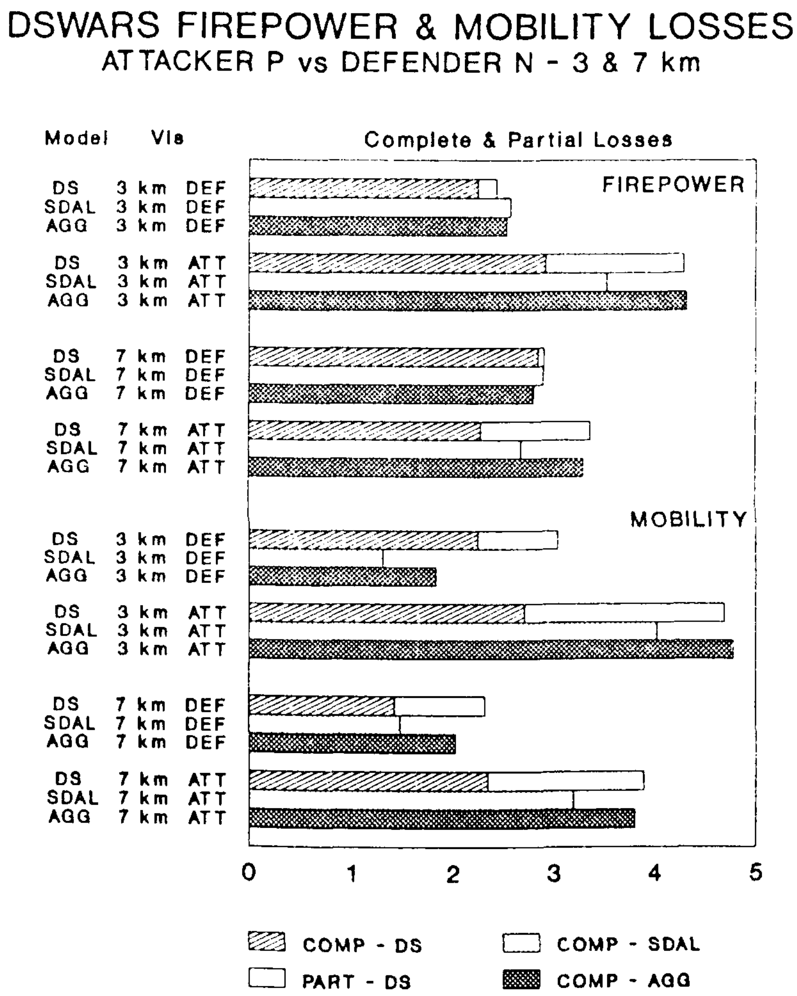


Figure 5. DSWARS F and M Losses - DS, SDAL, and AGG Cases

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SUBJECT:

The Degraded States Weapons Analysis Research Simulation (DSWARS): An Investigation of the Degraded States Vulnerability Methodology in a Combat Simulation

REASON FOR PERFORMING THIS EFFORT:

To determine if Degraded States vulnerability metrics can be implemented in a combat simulation model, and determine differences from using SDAL metrics.

MAIN OBJECTIVES OF THE EFFORT:

Develop a ground combat simulation to implement the Ballistic Research Laboratory's new Degraded States vulnerability methodology, and conduct study comparing force level results using SDAL vulnerability metrics versus Degraded States vulnerability metrics.

SCOPE OF THE EFFORT:

Modern tanks firing main gun.

IMPACT OF THE EFFORT:

a. For tank-versus-tank cases, these results suggest that, historically, the past use of SDAL vulnerability metrics as though they were complete loss of function in force-level models has given numerically acceptable results.

b. For tank-versus-tank cases, results indicate that DS-Aggregated probabilities can be used as an alternative to, or mixed and matched with, SDAL metrics.

c. AMSAA sees no need for changing higher resolution force effectiveness models at this time.

CONTRACTED ADVISORY AND ASSISTANCE SERVICES:

None.

SPONSOR:

Model sponsor is U.S. Army Materiel Systems Analysis Activity

PERFORMING ORGANIZATION/POINT OF CONTACT:

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Gary R. Comstock